4. Interdependencies and Cascading Effects

The development of a specific Community Disaster Resilience Plan requires an understanding of the building and system interdependencies and the potential cascading effects that can occur. Chapter 1 provided an overview of the framework development goals and process. This framework is intended to allow communities to understand their social and economic structures and develop recovery strategies that will allow them to be resilient to natural and manmade hazards as well as other unanticipated disruptions. Chapter 2 provided guidance for defining a community's social and economic structures and their dependence on the built environment. Following Maslow's hierarchy of needs – survival, safety and security, belonging, growth and achievement - provides a means of defining community resilience. Chapter 3 defined a vocabulary and structure for the Community Disaster Resilience Plan in terms of the hazards to be addressed, defined performance levels related to the degree of damage and recovery time, for defined clusters, that is permissible for each of the built environment sectors. Recovery times are defined for the clusters and organized around four categories within the built environment and three phases of recovery. Chapters 4 through 9 provide detailed guidance for developing the plan. This chapter deals with the need to consider the interconnectedness of the various buildings and infrastructure systems when setting performance goals for community recovery.

4.1. Introduction

The goal of the community disaster resilience plan is to determine "the performance needed for the various clusters (groupings of buildings or systems of common function) of the built environment to protect a community from significant and non-reversible deterioration." This is done by defining an orderly and rapid process for managing recovery that includes the just-in-time availability of a sufficient number of buildings in each of the designated clusters and infrastructure systems that support them. To achieve the goals, each cluster's performance depends not only on its primary function but also on the interdependencies between clusters and the interdependencies between infrastructure systems that support them. These interdependencies need to be addressed during the process of setting the performance goals in order to avoid cascading failures of multiple systems.

Cascading failures occur when the failure of one part triggers failure of successive parts downstream. It can occur within one system, such as a failure that cascades through the power grid when one component fails causing an overload and subsequent failure of other components in a sequential manner. It can also occur between systems when the failure of one system causes the failure of other systems. A multiple hour loss of power in a community can cause failure in the cell phone systems if there is not back up power to maintain the cell tower batteries. Intra-system cascading failures can affect power transmission, computer networking, mechanical and structural systems, and communication systems. Inter-system cascading failures can affect all buildings and systems.

Identifying the interdependencies and potential cascading failures is the first step. Mitigating their possibility and consequence and setting balanced goals can be done by adding redundancy, over capacity, and in some cases weak links that cause constructive isolation of systems that do not need to be interconnected. Governance processes and public policies also play a key role in orchestrating mitigation programs and in recovery management.

4.2. Interdependencies of Building Clusters

The resilience framework defined in Chapter 3 organizes the Community Resilience Plan around the three phases of response and recovery using four categories of building clusters. The first phase, focused on immediate response, is expected to last for days, and requires building clusters that serve as critical facilities and those that provide emergency housing to return to full functionality. The second phase, focused on restoring the workforce, is expected to last for weeks, and requires building clusters that provide housing and all the neighborhood level services needed including the schools. The third phase

focuses on activities and building clusters that are needed for the economic and social base of the community to fully recover. Each category has a unique set of interdependencies as is introduced below.

4.2.1. Critical Facilities

Critical facilities, as defined in Chapter 3, are a small number of building clusters that need to be usable immediately after an event to organize and direct the emergency response, secure the disaster area, and provide a safe environment for emergency responders. With the exception of access and housing for responders, the degree of interdependence on other clusters depends on their ability to operate in isolation using emergency power, an independent communication network, and possibly on site housing and subsistence for the staff. Access routes need to be established immediately for use by staff, users, and supply vehicles that are needed to replenish on site supplies including fuel, water, food, medical supplies, etc. Performance goals need to represent an appropriate balance between having the needed supplies on hand to operate independently and defining restoration times that are achievable.

4.2.2. Emergency Housing

The need for Emergency Housing for emergency responders, and displaced individuals and animals occurs immediately and is often met by using schools, shelters, hotels, conference centers, residences that are safe to “camp in” (shelter-in-place), etc. Food, water, security and sanitation needed to protect public health are usually provided at centralized locations. During the response period, there is a limited need for transportation, power, and communication. Current thinking says that it is best for residents to shelter in their homes, neighborhoods, or within their community. Recovery performance goals should address that possibility.

The inability to provide sufficient emergency housing can lead to a mass exodus from the community that could cascade into a loss of the workforce and ability to restore the economic base of the community. Performance goals need to be based on realistic estimates of the number of displaced workers and emergency responders that need to be accommodated, and the availability of adequate facilities within or adjacent to the community.

4.2.3. Workforce/Neighborhoods

Restoring fully functioning neighborhoods is key to providing the workforce needed to restore the economic vitality of the community after an event. Personal residences and the schools and businesses that support them need to recover fast enough to give the population confidence to stay and help with the restoration (tip-in) and to keep the small neighborhood businesses viable. There is a strong interdependence between where people live and where they shop, their kids go to school, they receive professional services, they worship, and they gather together. All of these activities need to recover in the same time frame. During this period, special attention must be paid to the needs of the disadvantaged and at-risk populations who will require a higher level of assistance.

If people are unable to shelter in their neighborhoods, the small neighborhood businesses they depend on will lose their client base and close. Once they close, they rarely can reopen when the people return. This in turn cascades into delays in the availability of the stable workforce needed to restart and restore the community economy.

The condition of the built environment that supports residences and neighborhoods is one of the keys to preventing the cascading failure to replenish the workforce. While the emergency response period will be over within days, the workforce needs to be re-established in weeks if the community is to restore its vitality to the pre-event levels. Significant structural damage to buildings and lifeline systems cannot be repaired within a few weeks. It takes months. Buildings need to be usable while being repaired or temporary facilities must be created in which they operate. The transportation, energy, water, waste water, and communication systems that support these clusters need to be restored within a few weeks. The need

for schools to be able to reopen is a key contributor to creating a stable and productive living environment.

4.2.4. Community Recovery

Restoring a community from a major event will provide a significant, short term stimulus to the economy due to the accelerated construction activity that is financed with the new money that flows in from government, insurance companies, large businesses, private savings and developers. In order for this natural occurrence to successfully jump start the local economy, there has to be a governance structure in place that approves reconstruction rapidly while protecting the community's interests and that can seize the opportunity to build back better. The key interdependency at this point is between reconstruction and governance. Any stall or stalemate in the decision making process quickly cascades into a stalled recovery and lost opportunity to use the construction activities to restart the economy.

It is a fundamental right of building and lifeline owners to maintain their properties under the codes they were originally constructed. Many believe that when a disaster causes damage, they can be rebuilt to the same standard. Building standards as they relate to disaster resilience have been maturing rapidly for the past 100 years and the recent interest in sustainability and building to limit damage is accelerating the change. Unfortunately, this only affects the construction of new buildings and systems. A natural disaster provides an opportunity to require repairs and restoration work to meet higher resilience standards set by communities. To be effective and enforceable, that requirement must be institutionalized well before the disaster occurs.

Community health and sustainability depends in part on sound urban planning that continues to adapt to changing conditions. Major changes in land use and zoning are often needed in communities, but they are not possible because of the cost and inertia surrounding the existing conditions. A significant disaster provides an opportunity and the needed funding to make major changes, but these are not generally possible if introduced during the aftermath of the disaster. They must be developed, properly vetted and included in the Community's General Plan so that their implementation can be accelerated in the post event recovery and reconstruction period.

4.3. Interdependencies among Infrastructure

All infrastructure systems – transportation, energy, water, wastewater, and communication – are interdependent because of the services they provide each other, but also because of the cascading impact of the failures that occur. For example, everyone needs electricity, even generation facilities need electricity to restart. Electricity needs streets and highways to move repair crews and materials, water for cooling, fuel for generation, communication and a stable and safe environment to work in. A broken water line collocated with an electrical vault can flood the vault and shut down a distribution network.

A well-functioning resilient community understands these interdependencies and works to break down the traditional silos of silence between providers, facilitates development of recovery plans that restore services in an ordered manner, orchestrates publicly funded mitigation programs that resolve choke points and barriers, and has plans for recovery that minimize impact on the community.

4.3.1. Identifying Interdependencies

Understanding the interdependencies between infrastructure systems is a new and developing area of planning related to resilience and recovery from significant disruptions. It has benefited from focused research since the mid-90s that has taken two tracks – one related to specific modeling and analytical studies using engineering metrics, the other based on empirical evidence gathered from both providers and users. The analytical methods provide more numerical precision but suffer from complexity and a lack of data on the systems and the fragility of their components. The empirical methods are based in reality and the perceptions of their operators but suffer from inconsistency amongst system reporting.

There is ongoing research in both methods that will develop new tools to assist in community based studies.

There is an immediate need for a process to identify the interdependencies for a resilience framework and an empirical method based on historical data seems to be the most achievable for communities at this point. Such a method was used by the City and County of San Francisco Lifelines Council in 2013 and it can be applied to other communities. San Francisco reported their findings and recommendations in February 2014 (CCSF Lifelines Council, 2014). Their process followed these steps:

1. Form a lifelines council of private and public infrastructure owners and provide a quarterly forum for them to meet, share planning activities to date, and discuss response and recovery issues, their interdependencies, and methods to improve the existing conditions.
2. For the extreme level of all prevailing hazards, characterize the expected level of damage in terms that can be related to infrastructure system performance from the view of the infrastructure provider. Figure 4-1 illustrates the restoration times estimated by the providers in the San Francisco study.
3. For each infrastructure sector, document the planned response and restoration process, likely dependencies on other systems and the understanding of other system dependencies on them.
4. Process the information and determine overall interactions between systems and the related dependencies. Identify areas with potential for cascading effects, occurrences of collocation, overlaps and hindrances related to restoration and recovery plans. Table 4-1 illustrates the interdependences identified in the San Francisco Study.
5. Develop a series of recommendations related to the next steps needed to better define the needs, advance collaborative planning where needed, prioritize the needed mitigation projects and identify funding sources for pre and post event needs.

Chapters 5 through 9 provide detailed discussion about the building clusters and each of the primary infrastructure systems. Each chapter includes the related Resilience Matrix and suggestions related to target performance goals in terms of usability and restoration time. The Summary Resilience Matrix presented in Chapter 3 combines all the information into a single page and serves as a clear statement of the interdependencies between buildings clusters and infrastructure systems. It should be apparent that the process of developing performance goals for building clusters and the infrastructure sectors that serve them is an iterative process that balances the needs with the capability of the existing systems and the availability and practicality of providing temporary services to meet the needs of the building clusters.

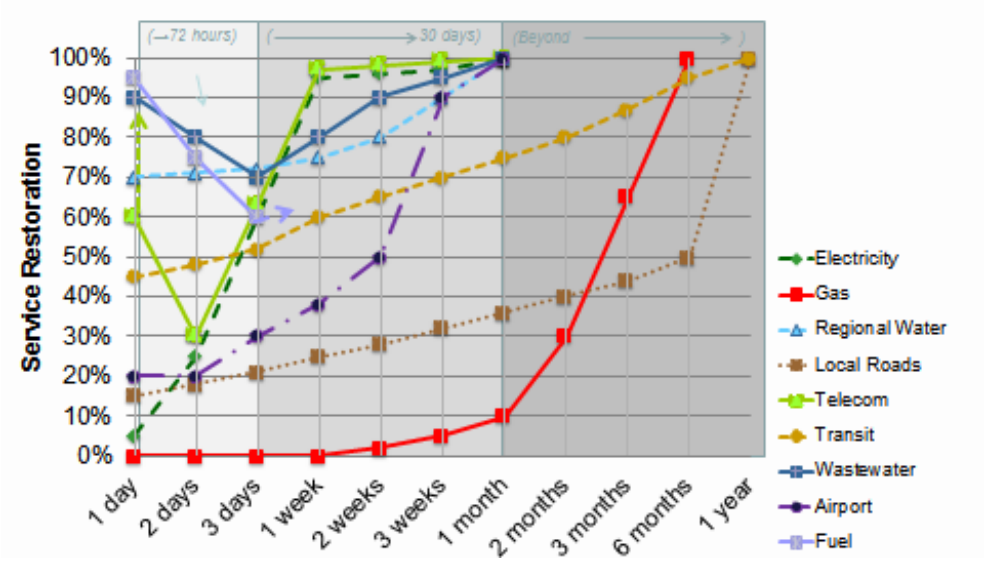

Figure 4-1. Potential Service Restoration Timeframes following a Scenario M 7.9 Earthquake on the San Andreas Fault. (CCSF Lifelines Council 2014)

Table 4-1. Infrastructure System Interdependencies following a scenario M7.9 earthquake on the San Andreas Fault. (CCSF Lifelines Council 2014)

Legend:

Significant interaction and dependency on this lifeline system for service delivery and restoration efforts
Moderate interaction and dependency on this lifeline system for service delivery and restoration efforts
Limited interaction and dependency on this lifeline system for service delivery and restoration efforts

The overall interaction and dependency on a particular system (read down each column

Operator's dependency on other Infrastructure systems (read across each row)

	Regional Roads	City Streets	Electric Power	Natural Gas	Telecom	Water	Auxiliary Water	Waste-Water	Transit	Port	Airport	Fuel
Regional Roads	General	Restoration Substitute	Restoration	Restoration	Restoration	Restoration		Restoration	Substitute		Restoration	Restoration
City Streets	Substitute Restoration	General	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration		Restoration
Electric Power	Restoration	Collocation, Restoration	General		Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration		Collocation	Restoration	Restoration
Natural Gas	Restoration	Functional, Collocation, Restoration	Substitute	General	Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration		Collocation	Restoration	Restoration
Telecom	Restoration	Collocation, Restoration	Functional, Restoration	Restoration	General	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration			Restoration	Restoration
Water	Restoration	Restoration	Restoration		Restoration	General				Collocation		Restoration
Auxiliary Water	Restoration	Functional, Restoration	Restoration		Restoration	Functional, Restoration	General			Collocation, Restoration		Restoration
Waste-Water	Restoration	Collocation, Restoration	Functional, Restoration		Restoration	Functional, Restoration		General		Collocation, Restoration		Restoration
Transit	Substitute, Restoration	Functional, Substitute, Collocation, Restoration	Functional, Restoration		Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, Restoration	Collocation, General	Collocation, Restoration		Functional, Restoration
Port	Restoration	Collocation, Restoration	Collocation, Restoration		Collocation, Restoration	Collocation, Restoration	Collocation	Collocation	Collocation	General		Restoration
Airport	Restoration		Restoration		Restoration	Restoration		Restoration	Collocation, Restoration		General	Functional, Restoration
Fuel	Restoration	Restoration	Functional, Restoration		Restoration	Restoration				Restoration	Restoration	General

Key to terms used in the matrix of interdependencies

- *Functional* disaster propagation and cascading interactions from one system to another due to interdependence
- *Collocation* interaction, physical disaster propagation among lifeline systems
- *Restoration* interaction, various hindrances in the restoration and recovery stages
- *Substitute* interaction, one system's disruption influences dependencies on alternative systems
- *General* interaction between components of the same system. (all systems would have general interaction issues, but some are more crucial issues for the system's potential disruption and restoration.)

4.4. References

Lifelines Interdependency Study/Report, City and County of San Francisco Lifelines Council, San Francisco, CA, 2014, http://www.sfgsa.org/modules/showdocument.aspx?documentid=12025